



## **The RAPSO Process**

**David G. Morris and Eugene S. Burke**

**Jet Propulsion Laboratory,  
California Institute of Technology**

## **12<sup>th</sup> AAS/AIAA Space Flight Mechanics Meeting**

**San Antonio, Texas**

**27-30 January 2002**

**AAS Publications Office, P.O. Box 28130, San Diego, CA 92198**

## THE RAPSO PROCESS

David G. Morris<sup>1</sup> and Eugene S. Burke<sup>2</sup>

### Abstract

The Jet Propulsion Laboratory's Resource Allocation Planning and Scheduling Office is chartered to divide the limited amount of tracking hours of the Deep Space Network amongst the various missions in as equitable allotment as can be achieved. To best deal with this division of assets and time, an interactive process has evolved that promotes discussion with agreement by consensus between all of the customers that use the Deep Space Network (DSN). Aided by a suite of tools, the task of division of asset time is then performed in three stages of granularity. Using this approach, DSN loads are either forecasted or scheduled throughout a moving 10-year window.

## INTRODUCTION

The Deep Space Network (DSN) is a unique worldwide network of large parabolic antennas capable of communicating with spacecraft deep in space. The National Aeronautics and Space Administration (NASA) has built the DSN and it has antenna diameter ranging from 26 to 70 meters. There are three complexes situated worldwide in order to provide continuous communication to a deep space spacecraft. The number of spacecraft has increased to the point where it is difficult to schedule the antennas to fully meet the requests of all users.

The Resource Allocation Planning and Scheduling Office (RAPSO) of NASA's Jet Propulsion Laboratory is chartered to divide the limited amount of tracking hours amongst the various missions in as equitable allotment as can be achieved. To best deal with this division of assets and time, an interactive process has evolved that promotes a collegial discussion with agreement by consensus between all of the customers that use the Deep Space Network (DSN).

Many of the spacecraft are built and managed by non-NASA agencies. They need to use NASA's DSN for reliable communications. This was recognized when these agencies began building deep space missions and the NASA process has been applied to these missions in order to use the DSN (Ref. 1). A significant worldwide effort has been invested into establishing standards for any spacecraft built to effectively communicate with the DSN and other agencies' large aperture antennas (Ref. 2). Approximately one third of the spacecraft routinely supported by the DSN are now foreign built or managed.

One Goal of the office is to facilitate strategic planning for NASA's future choices for mission funding by ascertaining the communications capabilities available to satisfy

---

<sup>1</sup> Asst. RAPSO Manager, Jet Propulsion Laboratory, California Institute of California, Pasadena, CA 91109.

<sup>2</sup> RAPSO Manager, Jet Propulsion Laboratory, California Institute of California, Pasadena, CA 91109.

the needs of every mission within this mission set. New approval requirements within NASA (Ref. 2) continue to require an assessment of a new mission's effect on the communications infrastructure prior to being approved. This requires that knowledge of the communication requirements for all missions needing the DSN into the future 5-10 years. The effect of this analysis has lead to increased number of antennas within the DSN or new requests for capabilities to cope with the demand for the communications capabilities of the DSN.

Besides the increasing number of missions supported by the DSN, there are other current and future concerns that will need to be addressed. Reduced manpower in mission operations, for example, lights-out operations require good planning. The extensively planned orbital operations of the Cassini mission will soon specify planned communication support down to the minute for the prime mission (2004-2008) of Saturn operations. Variable antenna pre-calibration time may provide increased utilization but cause some difficulty in creating schedules. Uniqueness of similar antennas provides varying capabilities that disrupt the ability to substitute one antenna for another requested one.

## METHODOLOGY

The RAPSO process is one that continuously looks forward in time. It is in effect an iterative process that assesses the communication needs of many users from the current day out to ten years and beyond. The fidelity of customer needs for spacecraft communication, engineering and maintenance of the antennas, and ground-based science increases as the schedule gets closer to the present. Mission plans change and it is important to monitor and capture these plans.

In order to meet these customer needs, the RAPSO Process is set up to work within three basic levels of information granularity. Figure 1 provides a simplified correlation between various teams of a mission and the RAPSO. The Mission Design Team computes the needed trajectory, spacecraft requirements and the initial communications used by the Resource Analysis Team to assess the DSN capacity to meet the mission's needs. In the near future (8 weeks up to 2 years), the Mission Planning Team determines when specific spacecraft events will occur and the Resource Allocation Team begins to allocate the antenna assets to the mission allowing spacecraft sequences to be generated. Mission Operations Teams monitor and assess spacecraft health and progress. Changes in communications support are coordinated with the DSN Scheduling Team. Generally, this is how missions and RAPSO interact over time.

<u>Organization</u>	<u>Relative Time from Present</u>		
	10 - 2 Years	2 years - 8 weeks	8 weeks to Present
RAPSO	Resource Analysis Team	Resource Allocation Planning Team	DSN Scheduling
Spacecraft	Mission Design Team	Mission Planning Team	Mission Operations Team

Figure 1. Simplified Spacecraft and RAPSO Organization Relative to Time.

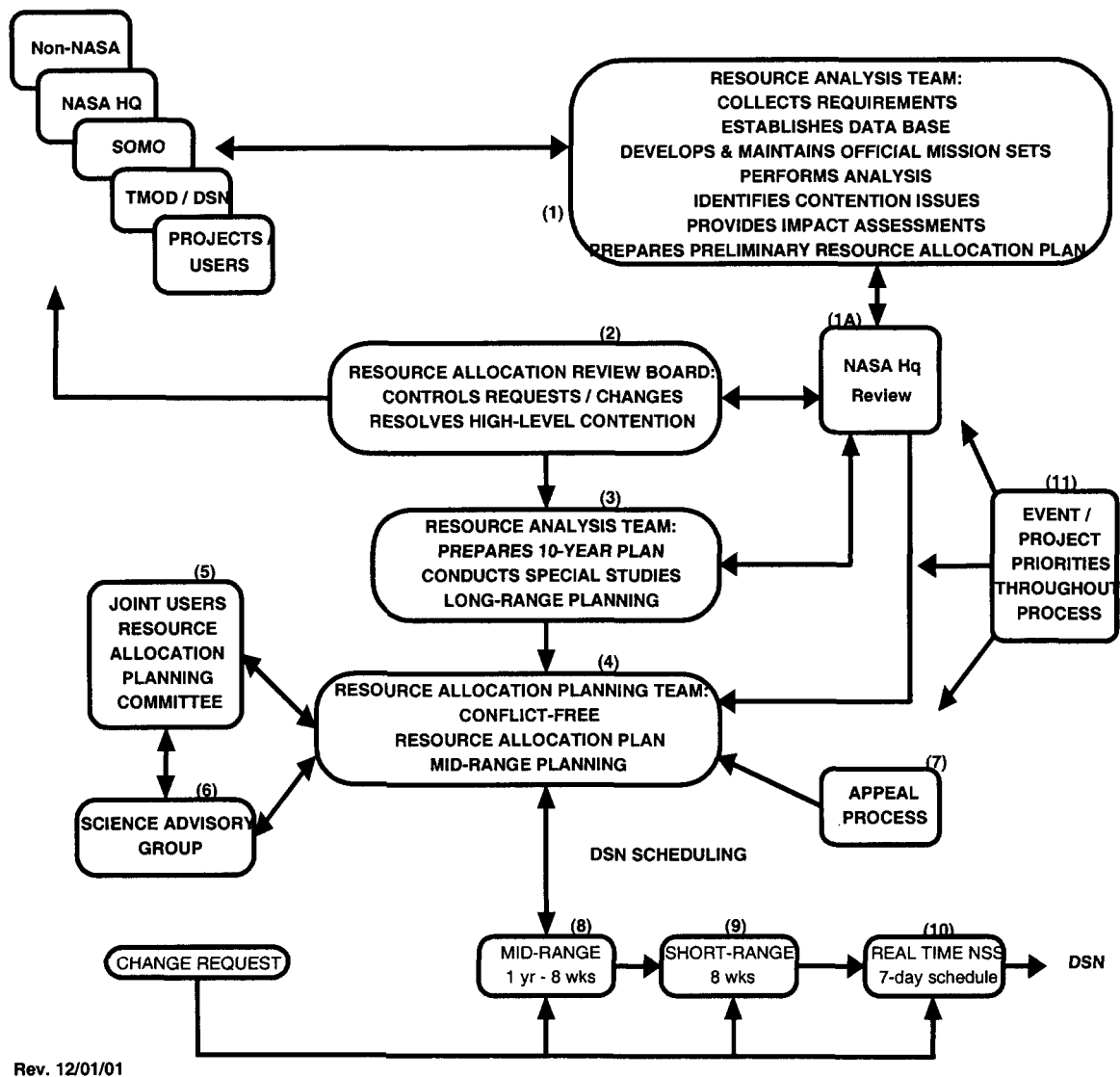


Figure 2. The End-to-End Resource Allocation, Planning and Scheduling Office Process.

The End-to-End Resource Allocation Planning and Scheduling Office Process is shown in Figure 2. An important area of Figure 2 is in the upper left corner where the customers and sponsor of the DSN are shown. The DSN supports current and planned customers from the United States (NASA and NOAA) and foreign agencies (European Space Agency and agencies from Japan, Canada, France and Italy). The rest of this section will describe how this process works and how each area interacts with others to accomplish the responsibilities of the office.

## **Resource Analysis Team**

The initial step before any analysis can be done is to capture the planned communications requirements for each of the users of the DSN. Each user documents their requirements annually in a Project Service Level Agreement (PSLA) (Ref. 2). A relational database is used to translate these requirements into mission events or phases with resource (antenna) linked tracking passes that are tied to each mission's viewperiod (Ref. 3, 4).

Three mission sets are used to categorize the ongoing and future missions that plan to use the Deep Space Network. Ongoing and approved funded missions that have yet to launch are contained in the DSN User / Mission Planning Set. Future missions that may or may not occur are kept in a Future Mission Planning Set. The third set, DSN 26M LEO User / Mission Planning Set, contains missions that are Earth orbiting missions that only require launch support, emergency or non-routine support from antennas of the DSN. The Appendix has a current copy of the Ongoing and Planned mission set.

There are a number of analyses, special studies and impact assessments that are requested of the Resource Analysis Team (Ref. 5). These are either routine or ad hoc analyses. Routinely, twice a year, a periodic product for a review is performed. Ad hoc studies generally are to answer specific questions and typically require an analysis for a new mission or regard a capacity issue. Each is dependent upon having an up-to-date database, forecasting tool and mission set.

The two routine analyses that are performed by the Resource Analysis Team is the Resource Allocation Review and the Long-Range Forecast and Capacity Analysis. The Resource Allocation Review work is explained later in this paper. The Long-Range Forecast and Capacity Analysis is published periodically and looks forward 10 years.

The initial requirements of a project are evaluated for impact to other missions as well as impact of the mission set on the new project. When a new project first submits their Project Service Level Agreement (PSLA), an analysis is performed to determine the impact to the requested communications via the DSN. The support of the mission is forecast with the present mission set of users. In addition, the impact of this project to other users is ascertained.

DSN capacity questions periodically arise. These questions often involve either the addition or closure of antennas. Sometimes non-DSN antenna assets are considered as well as the effect of capability changes within the DSN. Inherent to this question is when do you need antennas. If you know that answer, then you know when you could remove an antenna from operations for major implementation downtime. This is an ongoing activity for the Resource Analysis Team and is an important planning function for the DSN Engineering Office.

## **NASA Headquarters Code S Science Review Board**

This purpose of this review is to preview the recommendations that will relieve oversubscription of the DSN at the semi-annual Resource Allocation Review Board (RARB). It is an opportunity for prioritizing science and mission events while resolving

contention. All missions are effectively represented at the meeting. This step in the process had its preliminary review in January 2002.

### **Resource Allocation Review Board (RARB)**

Each year this review is held in February and August to resolve 26m / 34m / 70m contention. Participation by all affected Project Managers and Project Scientists, or their representatives makes this an effective review. Each of these participants is given a seat on the review board and has a stake in the outcome of the meeting.

This review is itself an iterative process within the overall process. Every February the current year (n) is dropped and a fresh year (n+3) is added for review. For example, the next RARB, to be held 12 February 2002, will address the years 2003, 2004 and 2005. The reason periods nearly four years into the future are looked at is that often recommendations may cost money that will need to be requested in order to implement agreed to changes. Thereafter, 2005 will be addressed up to five more times. The reason is that missions' communications needs and plans change periodically. By surveying each user every six months, the most up-to-date information is used for analysis.

The analysis first identifies periods of oversubscription that may be no more than a few hours on one day to whole months where many antennas are requested beyond their capacity. Analysis of these problems leads to recommendations to either increase the capacity or capability of the DSN or limit the defined requirements of the customers so as to fit within the available capacity. The present format reviews each and every month of the timeframe selected for contention.

Recommendations that are made to increase infrastructure are varied. The easiest suggestion may be the adding of antenna assets or modifying the date of initial use. In 1995, when analysis identified a period in late 1997 when Cassini was to launch and Mars Global Surveyor was to arrive at Mars and begin aerobraking, the suggested remedy to support both critical activities was to bring an antenna on-line one month earlier than planned. This alleviated the gap in coverage that would have occurred if the original date was used.

Recommendations that attempt to modify usage of the DSN range from mission planning or design change, compromised support or even deleted support. The longer the lead time, the greater chance a mission may accept a negotiated mission plan change. Otherwise, one or more missions may have to accept less than needed or requested coverage. Ultimately, there are additional negotiations needed to create actual schedules and that is the role of the Resource Allocation Planning Team.

### **Resource Allocation Planning Team (RAPT)**

After the Resource Allocation Review Board's contention analysis is complete, the job is just beginning for the Resource Allocation Planning Team. They produce a conflict-free plan by consensus resulting in a steady delivery of weekly schedules to the DSN Scheduling Team. An appeal route to continuing conflicts is defined later in this paper and is available to all customers.

This team is composed of Flight Project, Ground-based Science Observation Experiments, and DSN engineering and operations scheduling representatives. Presently, there are over 20 active Flight Missions, over 12 Radio Astronomy and Astrometry class experiments, three classes of RADAR observations (Planetary, Small Bodies (Asteroids and Comets) and Orbital Debris), numerous DSN Engineering Tasks and DSN Maintenance represented in weekly meetings.

Most deep space missions cannot 'joystick' their spacecraft. They need to plan spacecraft activities extensively and that includes sequencing the communications with the DSN. The planning horizon for some missions can be as short as the next communications support, but most want a few months to lock in communication periods so that detailed planning can be performed. Some missions have programmed the spacecraft to perform certain functions at specific times many years into the future. That is why the Resource Allocation Planning Team works from two months to two years into the future with the goal to be actively working at least six months ahead.

The Team works to achieve a conflict-free schedule. The work in progress is updated on 2 - 3-week intervals. The tool that is used to generate the initial schedule and maintain changes is called TIGRAS and it identifies conflicts (Ref. 3). These interim files are hosted on a wide world web page that provides access to all users.

Over the last year, it was difficult to plan further than three months ahead. Even with extra manpower used to generate initial plans, problems were encountered. One error that has been remedied was elimination of the use of out-of-date viewperiods. A new category of viewperiod was defined, the mid-range viewperiod, to better utilize the best available the trajectory file to create viewperiods months from the current date provide them electronically (Ref.4). It is now required of all missions to provide at least two years of viewperiods to the RAP. Presently, the working plan is beyond six months from the current date.

### **Joint User Resource Allocation Planning (JURAP) Committee**

The Joint User Resource Allocation Planning (JURAP) Committee is a forum for Project Mission Operations Managers, DSN Operations Manager and other project representatives to meet monthly and discuss past problems and future plans. It is also an opportunity to address contentions that arise from the Resource Allocation Planning Team and is the first of three methods to address appeals to contention resolution. Action Items from the Resource Allocation Review Board are reviewed monthly until closed.

### **Science Advisory Group**

The Science Advisory Group is a standing group, activated and chaired by the RAP Science Advisor, to address conflicts involving science data requirements or specific science events. In the past this avenue of contention resolution was used when multiple spacecraft wished to view the same object or event simultaneously. There would be contention in the ensuing communication with the Deep Space Network. At that point it is necessary to arbitrate which spacecraft combination merits the limited number of

available DSN communication antennas.

### **Appeal Process**

There is a process to petition any contention resolution among DSN customers. Any user may request this action. Table 1 shows the path that is available. There is an opportunity to raise issues at the monthly JURAP meeting and if that does not satisfy the user, meetings can be set up with the among the affected parties.

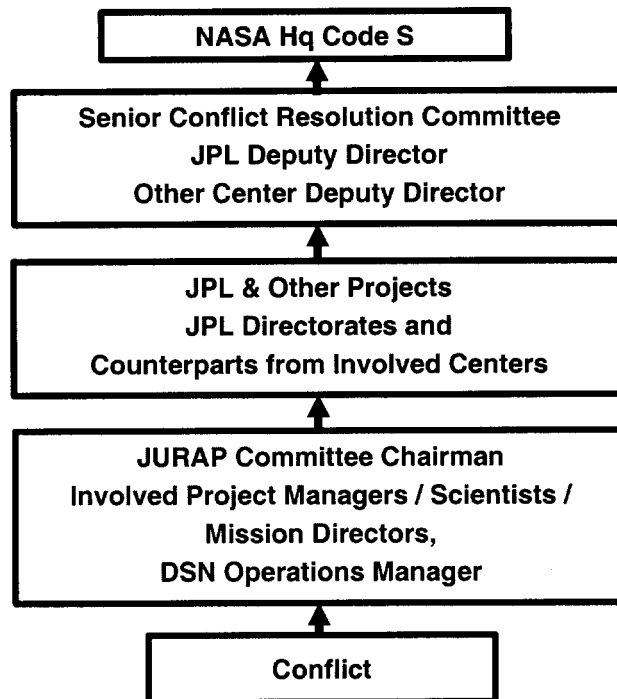


Table 1. Appeal Process is Available to All Users.

### **Deep Space Network Scheduling Group**

This group takes responsibility of the eight weeks to present conflict-free schedule. They work with requests for changes in support and coordinate needed changes as appropriate. Ultimately they will act as a recorder of events if changes are coordinated in real time by the Operations Chief of the DSN Operations Control Center.

Two areas that will affect this group the most are changes caused by launch changes and antenna failures. Generally, this group will work closely with missions ready to launch so that they can plan the effect of delays. For example, they find out the pertinent information necessary to replan supports such as knowing the general number of days in a row that a launch will be attempted before battery reconditioning would be necessary. Often a failure of an antenna component will either partially remove some capability of an antenna or completely remove it from service. Either way, close coordination with the affected missions is necessary. An alternate antenna may not be



available and necessitate negotiation among numerous missions.

The DSN Scheduling Team uses the Network Support Subsystem (NSS) as their primary tool. Viewperiods, tracking pass predictions and other ancillary products are produced to support the 7-day schedule.

## Event Priorities

Throughout the RAPSO Process a table of event priorities are used to help determine the relative needs of all the customers using the DSN. Table 2 provides this listing with definitions of each priority and specific clarifying criteria. In addition, common examples are used to apply this table to normal operations.

PRIORITY	ACTIVITY PERIOD & PRIORITY CRITERIA	EXAMPLES
1	Spacecraft emergency	Determined in real time
2	Mandatory for achievement of primary objectives. Support essential to spacecraft survival.	Periodic uplink to reset critical systems; launch; planetary orbit insertion; some TCMs*
3	Major, unique, scientific event. Time-critical.	Planetary encounter; major unforeseen scientific event
4	Minimum DSS maintenance, minimum support to maintain science validity.	Critical maintenance; short spans of data acquisition to assure data continuity.
5	Mandatory for achievement of primary objectives. Not time-critical.	Some TCMs*; includes spacecraft health and condition monitoring, and planetary astronomy.
6	Time-critical events not essential to primary mission objectives.	Includes radio astronomy.
7	Repeated scientific opportunities. Not time-critical.	Improvement upon minimum science return; includes host country radio sciences.

\* Trajectory Correction Maneuvers (TCMs) are considered to fall into two categories: (1) TCMs that are constrained to a particular time may be considered Priority 2, e.g., injection into planetary orbit; (2) TCMs that offer more flexibility in planning are considered Priority 5. The projects are expected to make every effort to avoid conflicts by coordinating their plans with the other users.

Table 2. Mission Event Priorities Are Defined With Criteria And Examples.

## CONCLUSION

The Resource Allocation Planning and Scheduling Office independently assess the mission demands of all users of the DSN. This allows the missions to focus on what they do best: design, build and operate quality spacecraft. By having an independent and impartial third party assess the demands on the DSN, projects can tune their mission design with the knowledge that all users are given a fair chance to receive communication time. In addition, an analysis of their plan using a thorough database of all other mission's

events that may impact their communication time is provided. The current process enlists cooperation from each of the missions and knowledge of their detailed mission plans so that a complete analysis can be done.

By dividing the task of scheduling the DSN into three levels of granularity, effective planning of network resources is accomplished. Long range forecasting of the DSN provides a reasonable mission set to evaluate the effect of new missions and can aid in developing the rationale for engineering changes and new implementation of assets in the DSN where warranted. Mid-range planning provides preliminary antenna allocation times that allow the spacecraft planners to begin to detail on-board activities that will be supported by ground communications up to two years into the future. DSN Scheduling provides the up-to-the-minute information on spacecraft trajectory and health with knowledge of antenna status to effectively update schedules necessary to coordinate changes among all users.

## **ACKNOWLEDGMENT**

The work described was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

## **REFERENCES**

1. G. Burke, R. Durham, F. Leppa and D. Porter, "Resource Allocation Planning with International Components," SpaceOps 92 Proceedings of the Second International Symposium on Ground Data Systems for Space Mission Operations, March 1, 1993, pp. 867-874.
2. D. Holmes and J. R. Hall, "Mission Requirements Methodologies for Services Provided by the Office of Space Communications," SpaceOps 92 Proceedings of the Second International Symposium on Ground Data Systems for Space Mission Operations, March 1, 1993, pp. 857-862.
3. C. Borden, Y-F. Wang and G. Fox, "Planning and Scheduling User Services for NASA's Deep Space Network," NASA Planning and Scheduling Workshop, Ventura, CA., 1997.
4. J. Kehrbaum and K. Kim, "The DSN Viewperiods Used for a Mission." AAS 02-221, 12th AAS/AIAA Space Flight Mechanics Meeting, San Antonio, TX, January 2002.
5. N. Lacey and D. Morris, "JPL RAPSO Long Range Forecasting." AAS 02-223, 12th AAS/AIAA Space Flight Mechanics Meeting, San Antonio, TX, January 2002.
6. J. Kehrbaum, "Using Available DSN Tracking Coverage as a Design Parameter in Mission Proposals." AAS 02-225, 12th AAS/AIAA Space Flight Mechanics Meeting, San Antonio, TX, January 2002.

## APPENDIX

<b>DSN Mission Set: Ongoing and Planned Projects</b>
<b>2001 Mars Odyssey</b>
<b>Advance Composition Explorer</b>
<b>ARISE</b>
<b>Cassini</b>
<b>Chandra X-ray Observatory</b>
<b>Cluster 2 - S/C #1 (Salsa)</b>
<b>Cluster 2 - S/C #2 (Samba)</b>
<b>Cluster 2 - S/C #3 (Rumba)</b>
<b>Cluster 2 - S/C #4 (Tango)</b>
<b>Comet Nucleus Tour (CONTOUR)</b>
<b>Dawn</b>
<b>Deep Impact</b>
<b>Europa Orbiter</b>
<b>Galileo</b>
<b>Genesis</b>
<b>Highly Advanced Laboratory for Communications and Astronomy</b>
<b>Imager for Magnetopause-to-Aurora Global Exploration</b>
<b>International Gamma Ray Astrophysics Lab</b>
<b>ISTP - Geotail</b>
<b>ISTP - Polar</b>
<b>ISTP - SOHO</b>
<b>ISTP - Wind</b>
<b>Kepler</b>
<b>Lunar - A</b>
<b>Mars ASI/NASA Science Orbiter 2009</b>
<b>Mars ASI/NASA Telecommunications Orbiter 2007</b>
<b>Mars CNES MSR Lander 2011</b>
<b>Mars CNES MSR Orbiter 2011</b>
<b>Mars CNES Orbiter 2007</b>
<b>Mars Competed Scout 2007</b>
<b>Mars Exploration Rover - A</b>
<b>Mars Exploration Rover - B</b>
<b>Mars Express Orbiter</b>
<b>Mars Global Surveyor</b>
<b>Mars Reconnaissance Orbiter</b>
<b>Mars Smart Lander 2007</b>

<b>DSN Mission Set: Ongoing and Planned Projects (cont.)</b>
<b>Messenger</b>
<b>Microwave Anisotropy Probe</b>
<b>MUSES - C</b>
<b>New Horizons</b>
<b>Nozomi (Planet-B)</b>
<b>Rosetta</b>
<b>Selene</b>
<b>Solar Probe</b>
<b>Space Infrared Telescope Facility</b>
<b>Stardust</b>
<b>StarLight</b>
<b>Stereo Ahead</b>
<b>Stereo Behind</b>
<b>Ulysses</b>
<b>Voyager 1</b>
<b>Voyager 2</b>